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Harbor Engineering

Civil Engineering

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HARBOR ENGINEERING

BY

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I recommend that the thesis prepared under my supervision by KOICHI HATTORI entitled Harbor Engineering be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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HARBOR ENGINEERING.

A-(1) Introduction.

Recent developments in ship building have greatly increased the dimensions of the ships, At the present rate of increase there will probably in 1920, be sea-going vessels at least one thousand feet in length (indicated by the curve in plate I). It follows that, to accommodate such vessels, harbors must have increased capacity. This increased capacity would require changes in three dimensions the length, the breath, and the depth.

In connection with the latest proposals for accommodating the biggest ships, the depth of the harbor or channel have been required to be as much as 45 feet (according to the Panama Canal.) It is realized that the Suez Canal was a great influence in building ships of moderate draught. This was simply because the canal afforded such economies that it could impress limitations on ship draught. But on the Atlantic route there are no such limitations. On the Pacific route, when the Panama Canal is opened in the near future, it is certain that the large vessels which are restricted from the Suez Canal will appear on that route.

Unfortunately harbor work is very dependent upon experience, especially that gained by failures; and as the nature of the improvement is permanent it is very difficult and expensive to reconstruct one already existing. We are now facing the great problem of accommodating vessels of increased size. Whether improved or reconstructed, the harbors on the world's commercial highway must be enlarged, as many are becoming too small for the larger vessels.

The purpose of this thesis is to discuss the general consider-

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ations for the design and construction of a harbor.

(2) Classification.

Harbors may be divided into four general classes, namely;naval, fishery, refuge and commercial. In this work, only the commercial harbor will be treated.

(3) Function of harbor.

A port is a gate-way between two transportation realms. On the one hand, the open sea offers the best and cheapest route for traffic with all the world. On the other hand, the land , with its road ways and inland water ways carrys the commodities of the great commercial centers.

A port becomes a great commercial focus in proportion as certain factors are developed with the flow of commerce. The production of goods in the inland may find a market by way of the port. The richer the inland, and the larger the flow of goods, the greater the possibilities of the port. As an inland develops its export trade, it becomes an active market for importation of goods from other regions, and in this way the business of the port will be increased. A port becomes greater as it develops the facilities for the flow of commerce, and reduces the difficulties incident to changes in the character of the transportation.

(4) Requirements of a good harbor.

The following appear to be the accepted requirements; A good harbor shall give anchorage and refuge for vessels in time of storm.

A good harbor should be both broad and deep enough to accommodate the largest vessels.

It should have devices for facilitating the loading and unloading of the vessels.

It should have a belt-line rail-way connection between general water traffic and adjacent railroads, if possible local industries.

It should be provided with a ship repairing and building system.

It should have good organization and good regulation and control.

(5) Preparation for designing a harbor.

Each different locality has its own peculiarities and therefore each particular case must be considered carefully in designing a harbor. From this study it appears that the following are the most important items included in such a study;

(a) General Census

(b) Topographic survey

(c) Sounding

(d) Boring

(e) Wind

(f) Waves

(g) Tide and tidal current

(h) Silting and littoral current

(i) Ice

(j) Materials for construction.

(a) General census.

Under this item, the nature of the port at the present as well as the probable future character should be carefully investigated. This is of great importance for the determination of water area of the outer and inner harbors, and the preperation for the future extension. The following are the principle parts of the census;

Population.

Financial condition.

General traffic and the amount.

Special traffic and the amount.

Relation to other ports.

Value of the port, prominent peculiarities.

Vessels; Kind of vessels, number of vessels, tonnage, maximum number and tonnage of vessel in harbor a same time ,number in particular season, rate of increasing size of vessels .

Future development of shipping, and opportunities of commerce and industry.

(b) Topographic survey.

A comprehensive and detailed survey should be made to ascer-tain the degree of the exposure of the harbor.The waves which occur in the harbor depend upon the exposure of the side from which shelter is most needed. In this respect, the determination of the position of shoals, island and coast, and distance to the opposite nearest land are desirable.

The triangulation should be made including all the harbor and vicinity, and should establish permanent marks which will be used as a basis for the sounding, boring, the observation of tidal currents and the determination of the character of the sea structures.

(c) Sounding.

Sounding should be taken at sufficiently short intervals to admit contours being accurately laid down. Special care should be taken over rocky ground to show actual elevation of bed as it is usually very irregular. The nature of the sea bed should be also ascertained by procuring a sample of the bottom at each sounding. The depth of water should be refered to lowest spring tide.

A set of soundings of a harbor though complete cannot furnish all the necessary information regarding the nature of the

surface of bottom of the harbor and its changes. There should be a series of such soundings at the time of greatest and least disturbance, and extending over a number of years to exibit comparative changes and show the relative movement both in amount and direction.

(d) Boring.

The borings should be made to ascertain the nature of the strata below the bottom for a considerable depth and in sufficiently close intervals over the entire harbor. It is very important to determine the bearing power of the bottom where a heavy breakwater is to be built, or to ascertain the kind of machinery which is used to dredge the channel and to what extent it is used.

The careful examination of the material excavated should be made especially for the dock wall and the breakwater, as in the former case the design of the wall must be made to depend upon the nature of the foundation which affects the cost of such works very largely. In a dock surrounded by quay walls, the cost constitutes a very important part of the total expenditure, andin the case of the breakwater insufficient bearing power of the soil causes considerable settlement which leads the destruction of whole structures.

(e) Wind.

Wind is the generator of the sea waves which interfere with the construction of sea works. The harbor construction work should be arranged so as to take advantage of the working season.

It is important to observe the direction, strength, duration, relative frequency, and sequence of winds extending over as long a period as possible. Most authorities suggest that the result should be plotted using the Beaufort Scale.

(f) Waves.

In planning a sea structure, it is very important to secure in advance data relating to the waves. The following subjects are suggested by Captain D.D. Gaillard;

Frequency and violence of storms.

The direction and maximum velocity of storm wind.

Fetch or distance to opposite shore.

The direction of wave travel.

The maximum height and length of storm wave.

Whether or not waves break in advance of, or in the vicinity of, the site during storms.

The governing depth in the vicinity.

The character of the bottom.

Special waves which are not storm waves.

It should be remembered that the greatest wave which can reach the port occurs only once in several years. The observations should therefore be kept continuously as long as possible. The results of the observations may be checked by careful study either of the effect the wave action upon the sea works which are already built in the harbor or vicinity, or by a study of marks upon the rocky coast or cliff which has been subject to the continuous action of waves.

(g) Tide and tidal current.

Before and during a harbor construction, the tidal observation should be made by means of self-recording tide gauges. There are four important facts in the tide determination.

(1) The tidal establishment at full tide and change, or "Correct Establishment". This is of great value to vessels leaving or entering a tidal harbor.

(2) The highest and lowest spring tides.

The effective depth in a tidal harbor depends upon the lowest water. It is there-fore necessary to know the lowest spring tide.

(3) The average tidal ranges.

The wave action upon the sea works is most severe at the average low and high tide. The wider the range of tide the stronger and heavier the sea-structure should be.

(4) The datum- average spring water-level.

From the point of sanitation in a harbor, navigation of vessels, and maintainance of the depth of water in a channel, it appears from this study that the following items should be carefully investigated;

Maximum and minimum velocity of tidal current.

The direction of tidal current.

The effect of an ocean current.

Currents caused by storm.

(h) Silting and littoral currents.

In a closed harbor , it has been often experienced that a considerable amount of silting caused the harbor to become shallower and ultimately become choked and rendered useless. The careful study of the silting therefore should be made before attempting sea construction as break-waters and jetties.

Where littoral currents exist, they cause the sand and shingle to travel with the counter action of waves. If the nature of the current varies as the weather changes, careful study in respect to this is required. The investigation should include the coast for a long distance on either side of the site of the proposed work.

Small coal, pieces of burnt clay or other easily recognizable material may be deposited at points alomg the coast in various depths of water, to determine the relation of strength and duration of the flood, ebb and littoral currents.

(i) Ice.

In some localities, there are many records of serious damage to the sea structure caused by the floating ice. The following items appear to be of value for reference in designing break-waters on sea works, where ice is encountered;

The extent of the ice field.

The magnitude of a floating ice.

The relative motion with wind and current.

(j) Material for construction.

Sand and stone are the materials most extensively used in harbor works. If such a material is found aboundantely in the vicinity of the site, the cost of construction will be reduced greatly. Many specimens should be collected and a comparative study according to the following items should be made;

Quality of materials,- physical and chemical.

Durability.

Specific Gravity.

Quantity.

Cost of transportation.

(B) The Breakwater.

(1) Purpose.

The breakwater is a structure built for the purpose of breaking or reducing the force exerted by the waves, thus producing the still water in the harbor. The main purposes of a breakwater are as follows;

To provide safe anchorage for vessels.

To facilitate loading and unloading vessels.

To protect the structures in the harbors.

(2) The Type Forms.

Breakwaters may be classified in two general types, namely, the vertical type and the mound type.

I. Vertical types.

The vertical type of the breakwater includes the following seven different forms of construction;

(a) Timber framing filled with rubble stone.

(b) Masonry or concrete blocks with a hearting of dry rubble stone.

(c) Concrete blocks laid in horizontal courses.

(d) Mass work of concrete.

(e) Mass work of concrete with concrete bags.

(f) Concrete blocks laid in sloping courses.

(g) Reinforced concrete caissons.

(a) Timber framing breakwater filled with rubble stone.

This type of breakwater has been extensively used in the Great Lakes of the United States. There are two destinct forms of breakwater in this class. One employes pile work (Plate II) and the other crib work (Plate III and IV).

The function of this type of breakwater is to encase the

rubble and prevent its dispersion, the rubble gives support to the framing by its weight.

In the break-water of pile work, the larger stone should be used for the faces of the breakwater and the piles should be well braced together as shown in the figure, (Plate II). The hearting is usually dumped from wagons.

In the second form of breakwater of timber crib work. the cross section should be square this being the most economical form. The crib is usually built in sections on the land, and sunk into place with or without a superstructure.

It is very important, in constructing either pile or crib breakwaters,to back up the same with rubble as quickly as possible, because upon this, the stability of the structure in a great measure depends, and frames, while impacked, are very liable to be displaced and damaged even by moderate sea.

Advantages and disadvantages.

This class of breakwater is best suited for shallow water where they are not to be exposed to very heavy sea, and especially as a dike for training the channel at the mouth of a river.

Where sutible materials can be obtained at reasonable cost the breakwater will be constructed quickly, and at considerably less cost than those built of solid masonry or concrete. But in general, the timber works are of temporary nature, and liable to decay between high and low water levels. Moreover it receives the attack of the teredo and other sea worms,unless the timber has been well treated and protected.

(b) Breakwaters of masonry or concrete blocks with a hearting of dry rubble stone.

A typical form of this class of breakwater is shown in Plate V. The dimensions are those of the Filrush breakwater.

It consists of three parts; the masonry or concrete walls on sea and harbor sides and the rubble hearting.

The vertical walls are built with or without cement morter and filled with loose rubble stone from wagons.

Advantages and disadvantages.

This class of breakwater is only suitable for the site where exposure is not severe. In constructing the breakwater expensive machinery is not required, and accordingly the first cost may be low as compared with other types of breakwaters.

The outer walls act as retaining walls separately as there is no connection between them and during a storm, the hearting acts as a wedge between the walls, its action being increased by the falling of the mass of water upon the road-way. This type requires exceptionally strong and heavy construction and proportional increase in the cost.

The failures of this class of breakwater are started by the ploughing out of the rubble hearting, and followed by the overturning of the walls which have lost their support. The breakwater therefore is most suitable as a landing pier where no heavy wave action exists.

(c) Concrete blocks laid in horizontal courses.

This class of vertical breakwater is illustrated in plate VI. It consists of concrete blocks laid in horizontal courses with broken joints, and mass concrete is deposited over whole width of the breakwater to make it form a monolithic mass.

The leveling of the foundation is most essential part of the construction. Any irregularity of the surface of bed should be removed, or filled with mass concrete, or concrete bags by the aid of divers.

On the prepared foundation below the low water level, the concrete blocks are laid "dry", those above the level set in cement and grout.

Advantages and disadvantages.

This form of breakwater is recommended for shallow or for moderate depth of water where the foundation is rock, as progression of the work is rapid.

It is very difficult and expensive to secure perfect contact of successive layers, especially below the low water.

Trouble is often experienced by the settlement of the dry set blocks. The blocks come to bear upon each other at a point or edge which is apt to cause breakage of the blocks, or they are liable to fall away from the monolithic work and be easily drawn out by the waves.

(d) Breakwater of mass concrete.

The typical section of this breakwater is shown in plate VII. The breakwater is of the monolithic concrete deposited within temporary timber forms.

This method of construction is very suitable to rocky ground and is not applicable to exposed situations.

Advantages and disadvantages.

This system of breakwaters possesses the following merits;

It is applicable either below or above water level, and to large and small works alike.

It may be carried out with a very small expenditure for constructing plant.

The tedious and expensive operation of leveling foundations is reduced greatly.

A large monolithic block may be constructed at a time.

The disadvantages are as follows;

It is a "good weather method", so there is no work for the employee engaged on the construction when it is interrupted by a rough sea.

The great difficulties in building the forms in water and to conform with irregularities of the surface of rock, thus increases the cost.

The interruption of the work and the lossof cement arise from the injury to the forms.

(e) Mass work of concrete with concrete bags.

In this class of vertical breakwater, the large canvas or jute bags containing from 4 to 20 tons of fresh mixed concrete form a base for a monolithic mass concrete above them as shown in plate VIII.

The purpose of using concrete bags is to prevent the cement from washing out when deposited under water.

The bag work is usually brought up to or above the low water and the temporary timber frames are built on the top of the bags to receive the concrete.

It is not desirable to expose a bag work face to the stroke of very heavy waves as there are usually some spaces between the bags. To protect the face of bag work, rip-rap wave breakers are used on the weather side as shown in plate VIII.

This class of breakwater is most suitable in shallow water and slight exposure, as it is not entirely a monolithic mass.

Advantages and disadvantages.

The merits of this method of constructing breakwaters are as follows;

It saves the cost of timber for the frames and labor.

There is less danger of cement being washed out when deposited.

The disadvantages are as follows;

The bag is liable to be torn while being deposited in the water.

The concrete in a bag is liable to be broken into pieces when lowered to the bottom.

It is also a"good weather method", and so it has the same disadvantages as the preceding class of breakwaters, to which reference is made.

(f) Concrete blocks laid in sloping courses.

This form of breakwater is used most successfully in almost all localities. The concrete blocks are laid in inclined position making an angle of 65 to 80 degrees with the horizontal axis, Which rests on the base of rubble stone, bags or mass concrete.

The inequalities at the quay level are adjusted by a capping of mass work which binds together the blocks which form the monolithic breakwater. Also the blocks are bound together not only by breaking joints with each other but by means of joggles of large size, formed by filling grooves with concrete in bags.

The typical form of breakwater of this class is shown in plate IX.

Advantages and disadvantages.

The advantages of this breakwater are as follows;

It is suitable for either the purely vertical type or for a combination with a rubble base.

It is the most suitable form for the site which is subjected to heavy wave action.

The injury resulting from settlement is less than in the case of other breakwaters of the vertical type.

The breakwaters may be built on any kind of sea bed or bottom.

The progress of construction of the breakwater is very rapid as it is laid from the top of the breakwater often by means of a setting machine.

One disadvantage is that there is a tendancy for the slope to become flatter during construction.

(g) Reinforced concrete caisson breakwater.

This is the latest type of the vertical breakwater as adopted in several places.

The reinforced concrete caisson as shown in plate IX, is built on the land and floated between the guides over a base previously prepared. Then by knocking out the pins, the caisson is sunk in place and filled with concrete rapidly.

The figure(Plate X) shows the caisson used in the break water at Zeebrugge, Belgium, which was 75 feet long, 27 feet wide, and of 7 thousand tons in weight.

The disadvantages of this system are as follows;

Extra cost of making a large steel skeleton.

Great skill is required to form the caisson properly.

The advantages of this system are as follows;

Rapid progress of the work.

Increased strength of breakwater.

It is most suitable for an open sea.

It is suitable for deep water work.

II. Mound types.

The mound type of the breakwater includes two different types of construction, viz:

(a) Mounds formed by rubble stone.

(b) Mounds of concrete blocks thrown together.

(a) Mound breakwater of rubble stone.

There are two distinct forms of breakwaters of rubble stone, those with and those without a superstructure. The two forms are shown in plate XI.

The former consists entirely of rubble stone thrown into the sea and allows the waves to form a natural slope. The latter has a vertical or sloped masonry structure on the mound.

It is evident that the mound type of breakwater is only applicable where there is an abundant and. good supply of suitable stone in the vicinity.

The advantages of these breakwaters are as follows;

Cheapness of material.

Simple methods of construction.

Rapidity of construction.

The disadvantage is the high cost of maintenance.

(b) Mounds of concrete blocks.

There are a few breakwaters which are constructed entirely of pell-mell block construction on account of the cost of concrete blocks. So the combination of rubble stone and pell-mell blocks is used quiet widely. Such combinations are very neumerous and a few of them are shown in plates XII and XIII.

The following are the most common types found in the Mediterranean Sea;

(1) Pell-mell mound of blocks placed upon the base

of rubble stone which is brought up to within 15 or 20 feet of low water level.

(2) A mound of rubble capped by pell-mell blocks to protect the sea-ward slope.

(3) A mound of pell-mell blocks backed up on the harbor side by rubble, to prevent the passage of silt.

(4) A pell-mell block mound with concrete or masonry super-structure.

(5) A rubble mound with super-structure and the sea-ward slope faced with pell-mell blocks.

(6) A low rubble mound with a vertical structure and with a wave breaker on the sea-side.

In comparison with the rubble mound the advantages of pell-mell system are as follows;

Less material required.

Lower cost of maintenance.

More durability.

Breaks up waves.

Checks the withdrawal of waves instead of rolling about.

(3) Design of breakwaters.

Before entering the subject of the design of breakwaters the item stated under "preparation for designing harbor" should be carefully studied.

I. Vertical type of breakwater.

The question of what the ratio should be between the static inertia of a mass of concrete or masonry and the dynamic force exerted by the waves, has not yet been accurately ascertained. However some rules have been derived, and according to one of the

authorities* the weight of the block should not be less than twice the weight of a mass of water equal to the cube of half the wave height. It has been found by experience that the rule does not hold good, if the length, breadth, and height of such a block differs much from each other. There is another rule based upon the following assumption which appears very reasonable and that is the assumption that the waves are as common cycloids. It is necessary to find out what dynamical force is exerted by the highest wave in the harbor and a section is designed to resist by net inertia the overturning and sliding effects.

The stability of the section thus found is very difficult of determination. The dynamical force above considered is only the direct horizontal component of the force, which is produced by the impact of the wave against the outside of the breakwater. But there are three destinct forces besides the horizontal component, according to the observations of Mr. Thomas Stevenson namely;

(1) The vertical force acting upward along the face of the breakwater, (2) The vertical force acting downward along the toe of the breakwater, and(3) the drawback of the wave after it has reached the breakwater.

These three forces are as important as the horizontal one. There are many records of the failures of the breakwaters caused by neglecting these forces of design. The three forces are not treated fully as they vary greatly upon the inclination of the face, and the outline of the breakwaters.

* Inst. of C. E. London, CLXVI.

† This may be calculated by the formula given by Captain D. D. Gaillard, U. S. Army or the actual observation with the marine dynomometers.

The only way to resist the forces is to effect a modification of the section above found by use of data which is obtained through the experiments.

The following are the valuable items of information with respect to the forces, and are useful in the consideration of the design of the vertical type of breakwater;

(1) Every block or stone should be rigidly connected with the others , to act as a monolithic mass.

(2) A string course of any projection in the sea-ward face should be avoided as it helps in the overturning.

(3) A capping with mass concrete deposited in place should be moulded in short lengths of about 15 to 20 feet, each section terminating with a vertical joint to prevent cracks caused by the slight settlement of the blocks below.

(4) All blocks should be laid as headers. The smallest possible surface will thus be opposed to the wave stroke.

(5) Batter, in the face of a breakwater is objectionable. It relieves the outer blocks of the lower course from weight, and facilitates their withdrawal by the wave action.

(6) A loose or weak hearting in a breakwater is dangerous.

(7) The pressure of a parapet causes partial settlement of the breakwater due to the unequal loading on the foun - dation, and it is likely to bring longitudinal cracks.

(8) The toe of breakwaters on both harbor and sea sides should be protected by the concrete bags or blocks from the scouring action of the littoral currents.

(9) The relation of the height and width of the vertical

wall to the height of rubble stone base should be determined by the economical consideration relating to the costs of the different parts.

(10) A rubble which forms the base for a superstructure should not be brought up above 12 to 15 feet of the low water of spring tide.

(11) The bearing-power of the foundation, except rock, should be great enough to support the weight of the breakwater, heavy machinery used during construction, and to resist the dynamical action of falling water upon the top of the breakwater.

II. Mound breakwaters.

In designing a mound breakwater, it is very difficult to use any rules for the stability of such a loosely built structure as the jet of water enters freely into the interior of the breakwater. How-ever the following considerations which are obtained from many experiments may be found very helpful;

(1) The slope on the sea-ward side of the breakwater should be flater than that of the harbor side, and especially so between the elevation of high and low water of spring tide where it should be as flat as 12 to 1 or 15 to 1, according to the depth of water, the height of waves, and the size and specific gravity of the material.

(2) The small stone should not be used as the surface stone on the sea-ward side. It is easily rolled about and and rounded by the ceaseless action of the waves , thus wasting material.

(3) The smaller stones may be used about 12 to 15 feet below the low water of spring tide where no disturbance

occurs.

(4) A moderate mixture of small material in the mound assists the stability of the breakwater, but the use of an excessive amount of small stones reduces the strength of the breakwater and causes unequal settlement.

(5) The placing of a vertical structure upon a rubble stone mound is very objectional. It increases scouring action upon the sea-ward slope which ploughs out stones from about 20 to 30 feet below the low water of spring tide.

(6) The pitching of the surface of a rubble mound as shown in plate XI is very objectionable. It faciliates drawing back of waves and disturbs the rubble at the toe of the pitching.

(7) The width of the mound breakwater at the foundation should be increased according to the bearing power of the sea-bed.

(8) In a pell-mell mound placed upon a rubble stone base the latter should be wide enough to allow of a level bench extending beyond the toe of the block slope.

(9) The size of blocks for pell-mell work should be determined by a careful study of the work already built in the vicinity and of the conditions at the site.

III, Effects of ice.

In the northern localities, the effects of ice should not be forgotten in designing either vertical or mound types of breakwaters or any other sea structures.

One effect of the ice is the formation of the mass upon

the structure, resulting from the freezing of the water thrown upon the breakwater by waves. This is a large additional load on the breakwater, and at the same time, it increases the area of surface exposed to wave action, and reduces the stability of the breakwater.

The floating ice on the sea- ward side of the breakwater is another serious matter, but if pack ice covers a broad area of the surface of water, it acts as a floating breakwater, and reduces considerably the wave action before the wave reaches the breakwater.

Still another effect of ice which is most dangerous to a sea structure is that which occurs when the surface of the water is covered with floating ice of firm pieces, and they do not act as a floating breakwater, but they are thrown by the waves against the sea structure and causes serious damage.

(4) Location of breakwater.

The location of breakwaters depends greatly upon the configuration of the coast line, the extent of sheltered area required and the location of the requisite depth.

At the same time, the location depends partly upon the type of breakwater adopted to suit the exposure of the harbor. In general, the vertical type of breakwater should be so located that the longitudinal axis of the breakwater should be placed at an oblique angle to the direction of the prevailing heavy storms to reduce the force of wave action against the structures. The mound type of breakwater should be laid out far enough to make the waves break squarely on it since if waves break obliquely upon a rubble mound they cause the stone to travel.

Still another fact to keep in view is the easy approach

during heavy gales for the vessels entering the harbor.

If the breakwaters are built too nearly parallel to each other near the entrance, it is very dangerous to vessels navigating between them as the vessels could not develop very much speed in this position.

Finally,the breakwater should be so located, as to accomodate the growth of the port and so as to admit of its easy extension when additional area is required.

(5) Construction.

In constructing the breakwaters, the following precautions should always be kept in mind;

(1) The materials to be used in the breakwater should be kept on hand in abundant quantities and sent out without any delay whenever weather or sea permits.

(2) All machinery should be kept in good condition.

(3) All tools and equipment should be placed in a safe place at the end of each days work.

(4) The end of the breakwater is the weakest point while the work is in progress, so the proper protection should be made for wave action when the days work is over.

(5) Work should not be left half done at any time.

The general methods of handling materials for constructing a breakwater are as follows;

I Pile driving.

For driving the piles of a timber framed breakwater, any methods may be applied to the extension of the work according to the conditions of the site. But a steam-hammer pile driver on a barge is most extensively used for this purpose,owing to the rapidity

and efficiency of its work and effectiveness of its blow.

II. Placing mass concrete work.

Depositing concrete under water to build a breakwater may be done by means of buckets or skips having hinged flap bottoms. The skips are filled with fresh mixed concrete and lifted by a crane and swung over the site where the concrete is to be deposited. Then they are lowered slowly to the bottom and the contents in them are discharged by releasing the catch from above water.

The most convenient way of depositing concrete is made by passing it through a chute or a trough. In this way concrete is mixed on a barge moored close to the site and gravitates down to the site through the tube or chute.

The latter method is very suitable for large scale work as the concrete falls out from the tube continuously. In both methods a great care should be taken that the concrete shall not fall out from any height.

Sometimes "bag concrete" is used to prevent rubble travelling or to level up inequalities of the rock bed. The bags are made of jute or canvas and are usually filled with concrete, being from about 5 tons to 20 tons capacity. In depositing bag concrete, either an iron skip having hinged flaps or lids, or a hopper barge may be used. The hopper barge is most suitable for handling large bag concrete each bag weighing as much as 100 tons.

III. Setting concrete blocks.

For setting concrete blocks in breakwaters, the over-hanging crane or titan is used conveniently. This moves back and forth on the breakwater allready built. There are two different types of the crane, namely the "rectangular motion crane" and the "radial motion crane." The former is suitable for use when the blocks

are carried on the top of the breakwater from the storage yard to the end of the breakwater where the blocks are to be laid. The crane has a carriage which moves transversely and longitudinaly to the axis of the breakwater on the cantilever arm. The block is carried out by the carriage and lowered to place and it is laid in the correct position by the aid of the divers.

The radial motion crane , is most suitable when the blocks are carried on a barge from the yard to the place. The carriage on the cantilever arm of this crane moves along in one direction only along the longitudinal axis of the arm. The block is lifted by the hook from the barge and swung over to the place and then laid in the course of the breakwater as described above.

The advantages of setting concrete by this method are;

(1) The stability of the crane. It can be used when a floating crane can not on account of rolling caused by waves.

(2) There is no trouble in mooring the barge as is often experienced with the floating crane.

(6) Material.

Material used in the breakwater should be of durability and high specific gravity. Durability of material is effected by erosion, the changes of the temperature, chemical action of sea water, dynamical power of waves and the floating ice. The material should be able to resist these destructive agents as much as possible.

High specific gravity is very important in selecting materials as "the force required to overturn cubes of the same size of different kinds is proportional to their specific gravity."

(a) Stone.

Stone used in mound breakwaters or in concrete as an aggregate, should be tough, hard, dense and uniform in texture. Basalt is very suitable for use in forming the rubble mound. Granite is also suited to sea works, but if it contains excessive amount of felspar and mica it is liable to disintegration.

Chalk is not suitable for sea-works, as it becomes soft under dissolving influences of sea water. Sand stones which are very hard and durable are well adopted for sea works.

(b) Sand.

Sand should be preferably silicious, clean, course, free from loam and other deleterious matter. It should be well graded, washed and screened.

A sea coast sand must be washed thoroughly before used as it contains a great amount of salt.

(c) Cement and concrete.

A cement containing an excess amount of alumina or other oxides of iron and less of silica is not used in sea structures as it is unable to resist the action of sea water. Although the sea water contains sulphuric acid in only a slight amount, nevertheless it acts upon the alumina or oxides of iron in the cement. This action produces aluminum sulphate or ferric sulphate which is soluble in water thus causing the destruction of the structure.

The following are the results of the investigations of the committee appointed by the international building material convention in Paris;

" (1.)The erosion of a sea structure of cement is caused cheifly by the production of calcium aluminum sulphate.

(2.)Cement should not contain more than four per cent of alumina.

(3.)It is better to replace the alumina by iron oxide as it is less harmful.

(4.)The dangerous effect of alumina in cement will be reduced by adding proper amounts of pozzolan which contains considerable amount of silica."

Many investigations have been made acting upon the above suggestions and the conclusions are as follows;

" The strength of concrete or mortar made by the mixture of portland cement and pozzolan gains with age,while those made by portland cement alone loses with age, in sea water".*

The other requisites for a good cement and concrete, are almost the same as that of any other engineering work.

(d) Timber.

Any kind of wood is liable to be attacked by sea worms to a greater or less degree. It is unwise to use any timber where sea worms are active. However, the use of timber under water , as a foundation work will be safe from the attack of the marine insects which is most serious between high and low water level.

Although creosoted piles last 28 to 30 years, it is still economically better to use the concrete piles.

* Report of Otaru harbor works.

(e) Metals.

Metals most extensively used in the sea works are cast iron, wrought iron, and steel. The durability of these metals depends upon the amount of salt or any acid in the water and the degree of exposure to the waves. There are many records about erosion of metals used in sea works showing quite wide variations. It is very difficult to fix a limit for their life in sea works.

The painting of the metals is done to prevent both the erosion and corrosion, but it is not applicable under water. It might be better that the metals be galvanized as such have been known to last for several years.

The use of various kinds of metals in the same place should be avoided because this causes galvanic action through the sea water and increases the erosion considerably.

(C) Channel Improvement.

(1) Surveys.

The improvement of a channel or estuary in a harbor is a most important and at the same time difficult item in harbor engineering.

Before deciding the work to be undertaken in the improve-ment of a channel, the following surveys should be made;

(1) Maximum and minimum discharge of channel.

(2) Maximum and minimum velocities.

(3) Kind and quality of sediment.

(4) Tidal effect upon water level and velocity.

(5) Silting.

(6) Wind.

(7) Difference between ebb and flood tide.

(8) Tidal currents and littoral currents.

(9) Materials of bed of channel and their extent.

(10) General topographic survey and hydrography.

In constructing or designing a channel or an estuary, the following physical laws as presented by Prof. L. M. Haupt, before the Engineer's club of Philadelphia, should be considered;

1 The resultant effect is that produced by the effort of nature to establish and maintain an equilibrium. Any improvement should therefore aim to aid and not to oppose it.

2 A force will carry a lesser load up a slope than it will roll down. Hence it will be found that the gentler slopes will face or oppose the current and the steeper ones the over-fall. Thus it can be de-

termined which way the resultant current has been moving and from whence came the sediment.

(3) The discharge of the ebb tide(being augmented by the land drainage), is greater than that of the flood when not affected by local conditions.

(4) The location where the opposing sea and land forces are most nearly in equilibrium, will be indicated by the relative permanance of the bottom.

(5) The intermediate front, where the action and opposition occur, will be well defined by the deposites, forming a chain of submerged breast works.

(6) It is easier to deflect or divert a force than it is to oppose it.

(7) Flowing water will follow the lines of least resistance and greater declivity.

(8) The resultant of a system of forces which are in equilibrium may be changed in direction and intensity by modifying the component forces.

(9) Any submerged obstruction to a tide or current which creates an overfall or produces lateral currents, contains the elements of its own destruction, by undermining.

The above laws will serve as a guide to determine the forces and agencies which have combined to produce existing effects and help to ascertain whether they are permanent or constant in their action, and whether constructive or destructive in character. Then it follows, that it may be determined, what remedy should be applied

to maintain or improve the channels.

(2) Construction of channel.

In constructing a channel the aim must be to direct and aid the natural forces tending to remove the bar and keep the channel open, and to protect them from having a counter effect. This will be accomplished by the following;

(1) Concentrating and directing the currents, more especially on the ebb, that their whole scouring power shall be utilized in forcing and maintaining the channel, so that the matter carried by outgoing tide shall be held in suspension until it is brought under the influence of cross littoral current or into deep water.

(2) Increasing the volume of water which passes over the bar at each tide. This will be done by enlarging tidal compartments within the estuary or harbor by means of dredging.

(3) Protecting the outgoing current by means of the breakwaters, dikes or jetties from the deflecting effect of prevalent heavy sea for such a distance as will enable it to carry the matter in suspension out to the sea.

These are the general methods with which channels must be treated. The application of the methods depend upon the local condition which should be carefully considered.

Dredging.

Dredging is a matter of considerable importance in connection with the construction and maintenance of a channel as the scouring forces upon the obstruction to be removed generally are limited by the reason that the strong currents are very dangerous to the navigation of the vessels, and the forces are no longer applicable upon the single boulders or rock.

The class of machines to be used depends upon the magnitude

of the operation, the facilities for disposal, and the conditions generally under which the work has to be carried on.

Dredging appliances may be classified as follows;

(a)--- Suction dredges,

(b)--- Ladder dredges,

(c)--- Dipper dredges,

(d)--- Grab dredges.

(a) Suction dredges.

The suction dredges or sand pump dredges consist essentially of a continous pipe or tube through sand or other light material is sucked up from the bottom.

The sand usually contains large volumes of water, about 90 to 96% of which has to be delivered into the hopper barge or through outlet pipes leading to the place where it is to be discharged.

This class of dredge is very suitable for removing sand or mud. If a suitable device, like cutting blades, is attached ed to the end of the suction pipe it is still applicable in clay or mud.

(b) Ladder dredges.

A ladder or bucket dredge consists of an endless chain connecting a series of buckets which traverse in succession on an inclined plane about two pivots or tumblers, excavating materials at the lower tumbler and discharging it into a chute while passing over the upper tumbler.

This dredge is a very efficient appliance when large quantities of material extending over considerable area have to be removed, owing to its continuous working when a practically uniform bottom is required. It cannot be worked in a swell or a shallow body of water and is not an economical machine in the matter of

power, as the dredged material is lifted by the machine about 25 to 30 feet above the water line, representing a corresponding waste of energy.

There are two forms of bucket dredges ; one is attended by hopper barges and the other is the combination of the hopper and dredger which conveys dredged material to the place of deposit.

(c) Dipper dredges.

The apparatus, consisting of a simple bucket at the end of a long lever or arm and is mounted upon a barge. The action of the bucket is that of an upward curved sweep against the bottom. The contents of the bucket are discharged into a hopper through the bottom of the bucket which is hinged.

It is capable of working in the stiff clay, the hard marl and boulders, and also will take hard rock with the assistance of a little blasting.

(d) Grab dredge.

These dredges are essentially segmental scoops, generally two or more quadrants, which rotate about a central pivot, meeting in the closed position, forming a semi-cylindrical or conical bucket. The apparatus is manipulated by means of chains in connection with the crane, which liftes the bucket.

The grab dredge is a comparatively cheap machine and is very usefull in removing silt, loose soil, boulders, and large pieces of blasted rock. It is suitable to be used in confined situations and for a considerable depth in exposed places.

(3) Maintenance.

In order to keep an open channel in continuous service, dredges should be used co-operatively with the natural forces.

Many devices, as sluice or floating deflectors have

been used for scouring away and preventing accumulation of sand, and it was found that they are applicable in a certain depth of water. Beyond the limit or to maintain the depth of water required for navigating of some vessels, it is always neccessary to use a dredge more or less.

To what extent the dredging should be undertaken in the channel is a large problem and it should be carefully considered in connection with the revenue , and the value of the channel.

(D) Docks.

I. Classes.

Docks may be classified as follows;

1. Wet docks or basins.
2. Dry or graving docks.
3. Lifting and floating docks.
4. Slips.

1. Wet docks or basins.

(a) Purposes.

The wet docks or basins are areas of impounded water, usually several acres in extent, within which vessels can remain afloat at a constant level, independent of external tidal action and free from waves thus facilitating the loading and unloading of the vessels.

There are two different forms of this kind of dock namely, the tidal dock and the closed dock. The closed dock has gates or caissons in order that the water may be retained at a nearly uniform level, while the tidal or open dock , as the name implies, has an open entrance.

The following are the comparative advantages and disadvantages of the tidal and closed dock;

(1) The ships can leave or enter at any time from the tidal docks.

(2) There is no trouble to open or close the gates or caissons in the tidal docks.

(3) The required depth should be kept below the low water level. An extra height of quay wall is needed or dredging of the bottom according to the range of the tide.

(4) The elevation of water changes frequently with the tidal dock, which is very inconvenient in unloading and loading vessels.

(5) There is probability of silting in the tidal dock where the tidal current carries with it a large quantity of suspended matter.

(6) The closed dock has the uniform or constant level of water. It is very convenient for mooring vessels and facilitates the unloading and the loading process.

(7) There is no danger from silting in the closed dock. The time for entering and leaving the closed dock is restricted by the closed gates.

(8) The extra cost of gates and gate machinery is required for the closed dock.

(b) Location.

The following considerations should be kept in view in the location of either tidal or closed dock;

Where the range of the tide is considerable, closed docks are required.

For the ships of great length, a dock is more necessary than for the ships of small size.

Where the harbor or anchorage is liable to surface waves of considerable height or of any ground swells, a dock is more necessary than where there is better protection.

In a tideless harbor, the tidal dock is most suitable. It should be located in the most convenient position for connection with the railroads and warehouses.

(c) Construction.

The general plan of the basin which affords the maximum accommodation combined with the greatest facilities for maneuvering ships, will depend upon the class of ships and the nature of the trade. In view of the increasing length of ocean going steamers, the docks should leave more than 800 feet width and 1000 feet length in turning basins. On the other hand, in determining the width of the basin , the care must be taken to reserve an ample area for wharfage purposes, railroads and warehouses.

The shape of the basin may be any geometrical figure, or of several figures in combination. The most suitable forms are the rectangular, the square, and the diamond. The square form offers an advantage of plenty of space for the turning of vessels, but would give a shorter available length of wharfage than a basin of rectangular form of the same area. The rectangular form is therefore commonly used. The diamond is a slight deformation of the square and when an entrance is located at one of the acute angles, it gives quiet a convenient form.

The proper proportion between the surface of the dock and its periphery should be considered from the economical point

of view. Any undue surface area on the required wharfage increases the cost of excavation, or dredging, and land area.

The introduction of jetties projecting out into the basin offers a convenient and economical means of increasing the wharfage. This should be kept in view in constructing a basin. An important point in dock location is the supply of fresh water to the basin, to prevent the stagnant water around the dock from becoming foul and unsanitary.

(d) Handling machinery.

The predominant factor which limits the rapidity and despatch in the operation of handling the cargoes between ship and shore is the economic method employed. The extra cost due to delays in connection with the berthing and departing of ships, imperfect or inadequate handling machinery, and the depreciation of the apparatus will reach an extravagant total. It has been authoritatively stated that in the case of one Atlantic liner alone, the loss of a single day per voyage is equivalent to $15,000 per annum.

There are many kinds of apparatus used in connection with the terminal facilities, such as light houses, gate machinery,

Cargo handling machinery is one demanding most attention, since it effects so great economy.

For the handling machinery, cranes (from half a ton to 150 tons or more) are most extensively used. They are divided into two classes, namely, moving cranes and fixed cranes.

Usually, the smaller classes of the moving cranes are used most conveniently in the loading and unloading of vessels.

(A) Moving cranes may be classified as follows,

(1) Locomotive crane.

This is the most useful of the many types of cranes

which can be used on a wharf or jetty. The cranes are constructed to fit any gage of track, and are operated accordingly by steam.

(2) Traveling bridge crane.

This type of crane is used very succesfully on the great lakes in the loading and unloading of iron ore. The crane is usually of cantilever type ,and operated by electric power. The gantry frame straddles the railroad, and travels back and forth along the coping level. A grab shovel which is operated by means of cables runs over the bottom chords of the bridge and is dropped into the hold through an opening in the deck of the vessel. The bucket or shovel moves transversely to the railroad and dumps the ore in the storage yard on the opposite side of the vessel.

(3) Floating cranes.

The floating crane is, of ordinary jib type mounted on a barge, and is a valuable adjunct to the equipment of a dock system. The cranes are constructed up to 100 tons in lifting power.

(4) Transporters.

This is a form of a vertical framework in the shape of the letter "A", at right angles to which the transporting beam is set. The frame is free to travel along the quay on a line of rails, and is steadied by a second line of rails placed at some distance above the quay level, so as to prevent overturning.

(B) The fixed cranes may be similiarly classified as follows;

I. Revolving cranes.

This crane is the cantilever type and revolves around the vertical axis. It is built to handle very heavy loads up to 150 tons or more.

II. Derrick cranes.

It is very difficult to employ large cranes among the

masts, yards, stays etc.of the vessels. In this case the derrick cranes are used conveniently.

2. Dry docks or graving docks.

Dry or graving docks are structures formed mainly below the water level, from which water can be temporarily excluded, in order that repairs to vessels may be effected. After the vessel is floated into the dock, the water can be removed by either natural or artificial means.

The method of construction to be adopted will depend greatly on the nature of the adjoining land. In general the side wall should be designed as a retaining wall to with-stand the pressure of the backing behind it. The main difference between an ordinary retaining wall and the side wall is that, while the backing material behind the former is homogeneous, the material behind the latter is heterogeneous. Also the reaction, an upward force, transmitted from the floor should be combined with that of the back pressure.

The following are the weights and forces exerted in dry docks;

The pressure due to the back filling.

The weight of the side walls and the floor.

The upward pressure of water acting underneath the floor

The water pressure in the dock.

The weight of ship.

In designing a dock, the above forces should be properly taken care of to insure stability.

The floor may be constructed of either cut stone or reinforced concrete. When the cut stone is used the vertical joints should be radialto form an inverted arch, by which the upward

hydraulic pressure is transmitted to the side walls.

In determining the dimensions of a dry dock, the following conditions should be well considered;

(a) There should be ample room around the ship to admit of efficient examination, repairing, sunlight, and ventilation for the bottom of the ship.

(b) A large size dock involves the additional cost of material and labor in construction.

(c) An excessive width increases cost of timber and labor of shoring.

(d) The sill of the dock should be placed as low as possible. The plan should follow as closely as possible the bow line of the largest vessels. This reduces the cost of construction.

(e) Every part of the dock should be water tight.

(3.) Lifting and floating docks.

The lifting and floating docks are structures of steel (or iron) or wood which are sunk sufficiently into the water to enable vessels to be placed over them. They are then raised by pumping the water out, and the ship is thus " put up" for repairs.

(4.) Slips.

Slips for small vessels consist of inclined planes which run into deep water with cradles or carriages which may be run out under a vessel. The vessel is then made fast to the carriage and drawn on top of it out of the water up the inclined plane.

The functions of all these docks are the repairing and construction of ships. In the construction and design of these docks both practical experience and wide observation are required. The designs are omitted from this study since they are separate problems in themselves.

Conclusion.

In conclusion it may be said that Harbor Engineering is such a large subject that it involves all kinds of engineering work. Most of the large harbor improvements have been made by the governments, and in most cases the government engineers have designed and constructed the improvements. There are many good books published on various phases of the work and a list of those found useful in this study are given in the bibliography. The most extensive work of investigation appears to have been made by the engineers of the United States government, but there is still much to be developed in the art of Harbor Engineering.

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Plate I

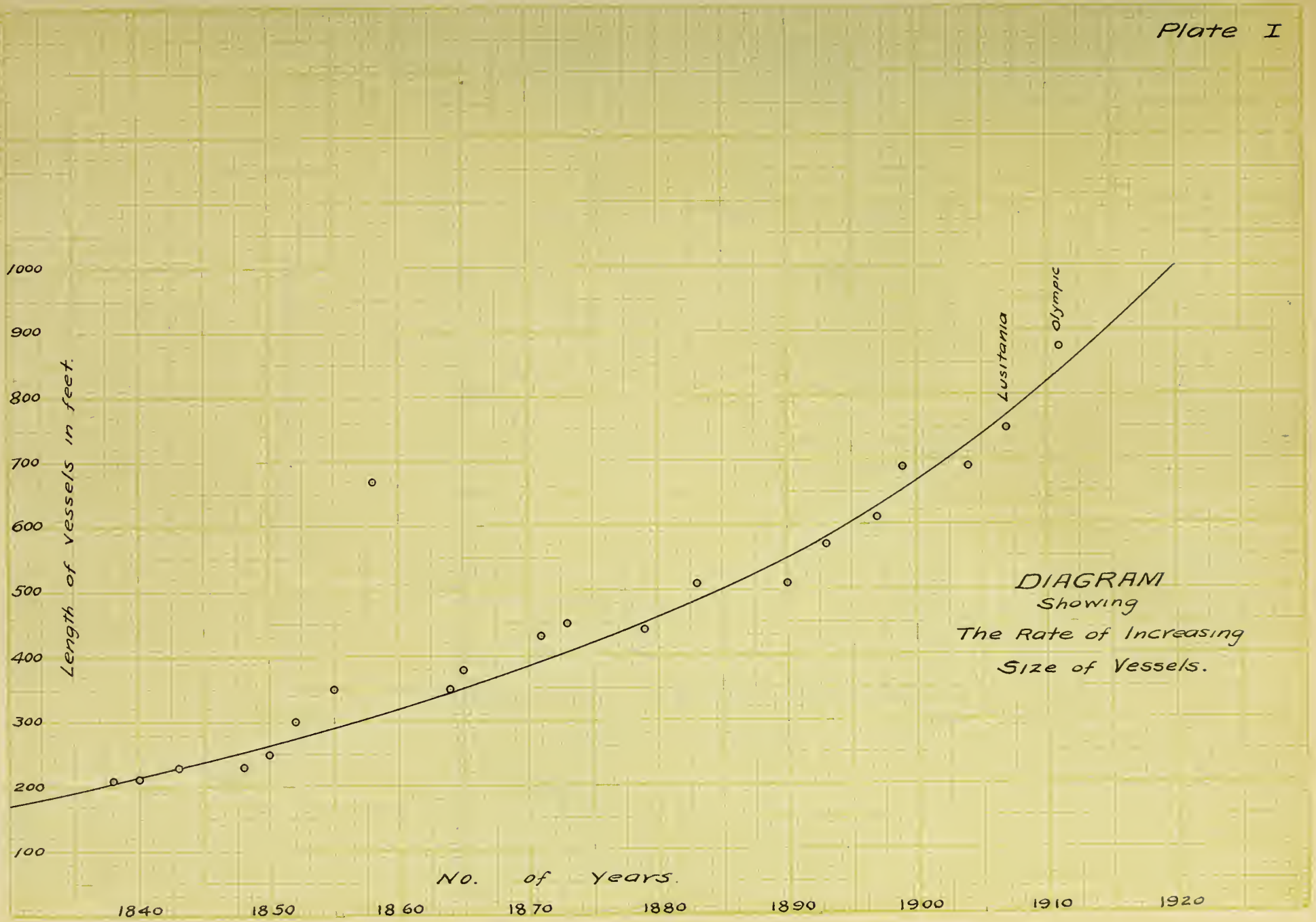

DIAGRAM
Showing
The Rate of Increasing
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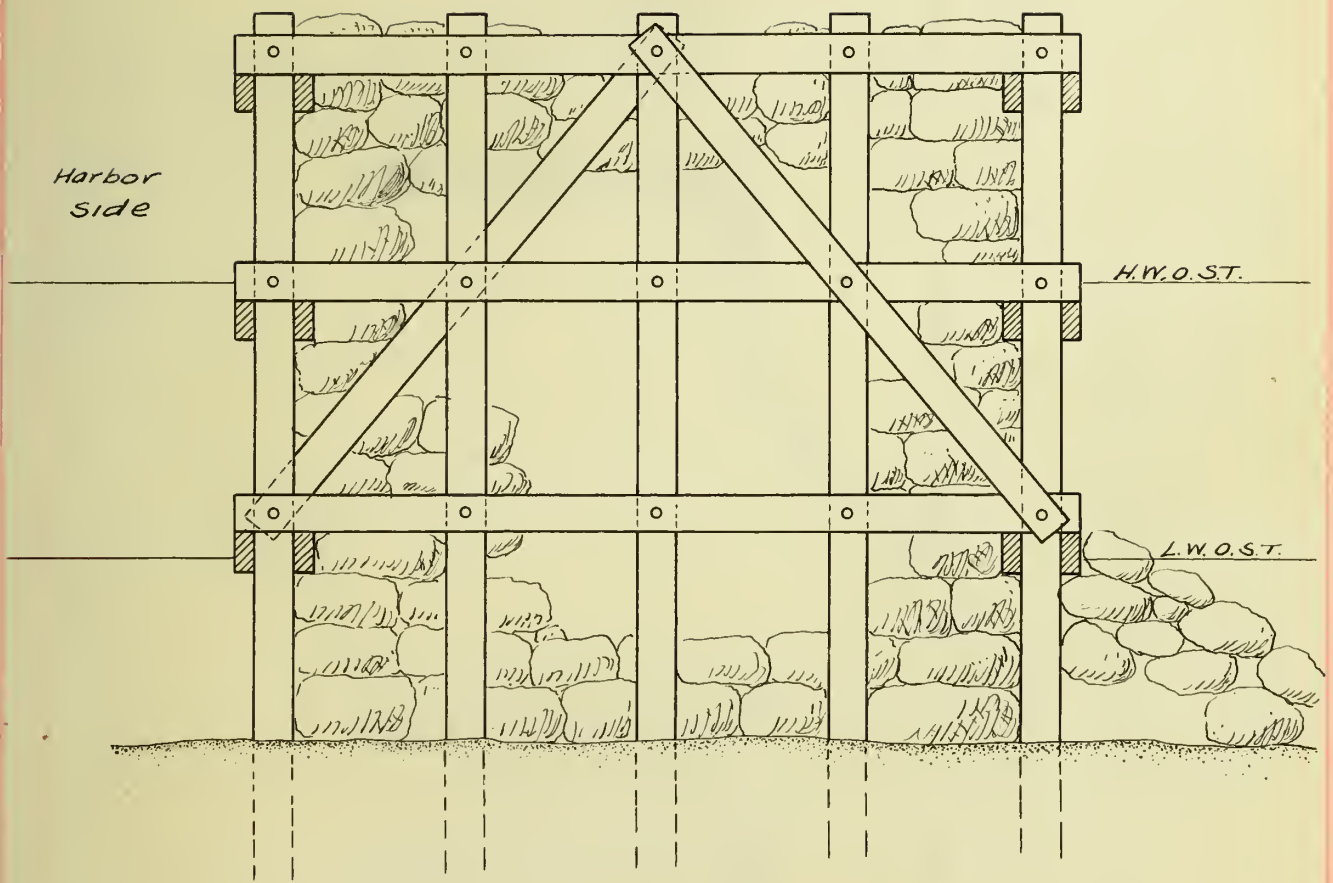
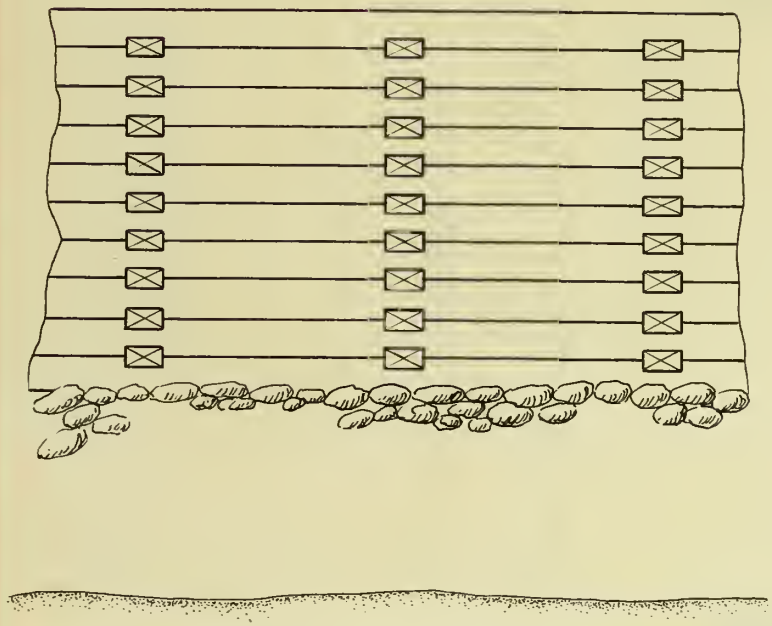
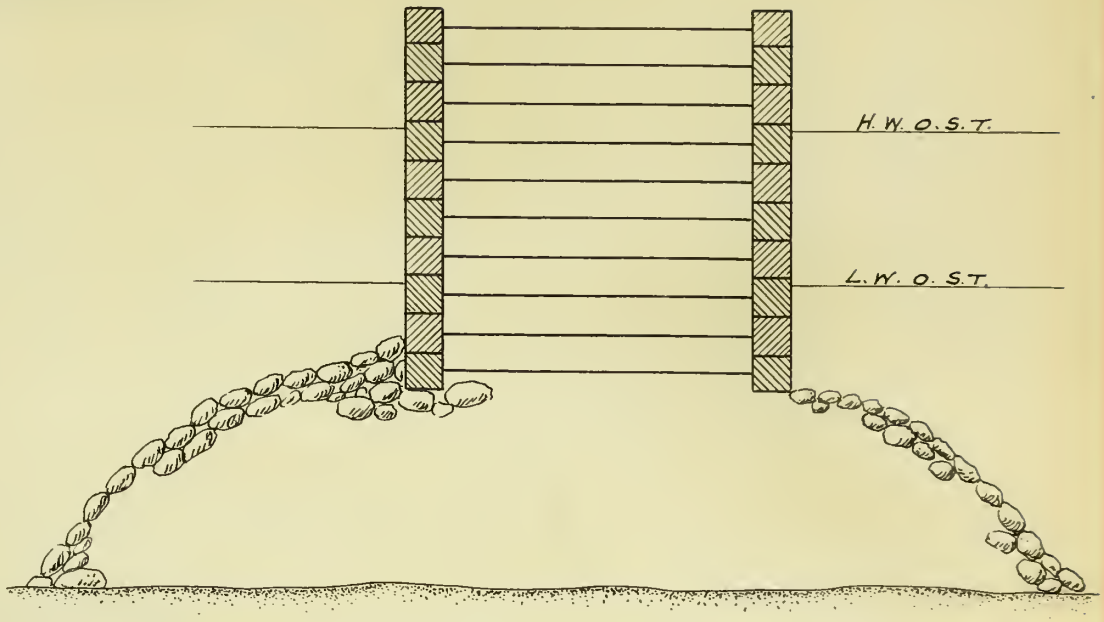


Cross section of Pile breakwater.

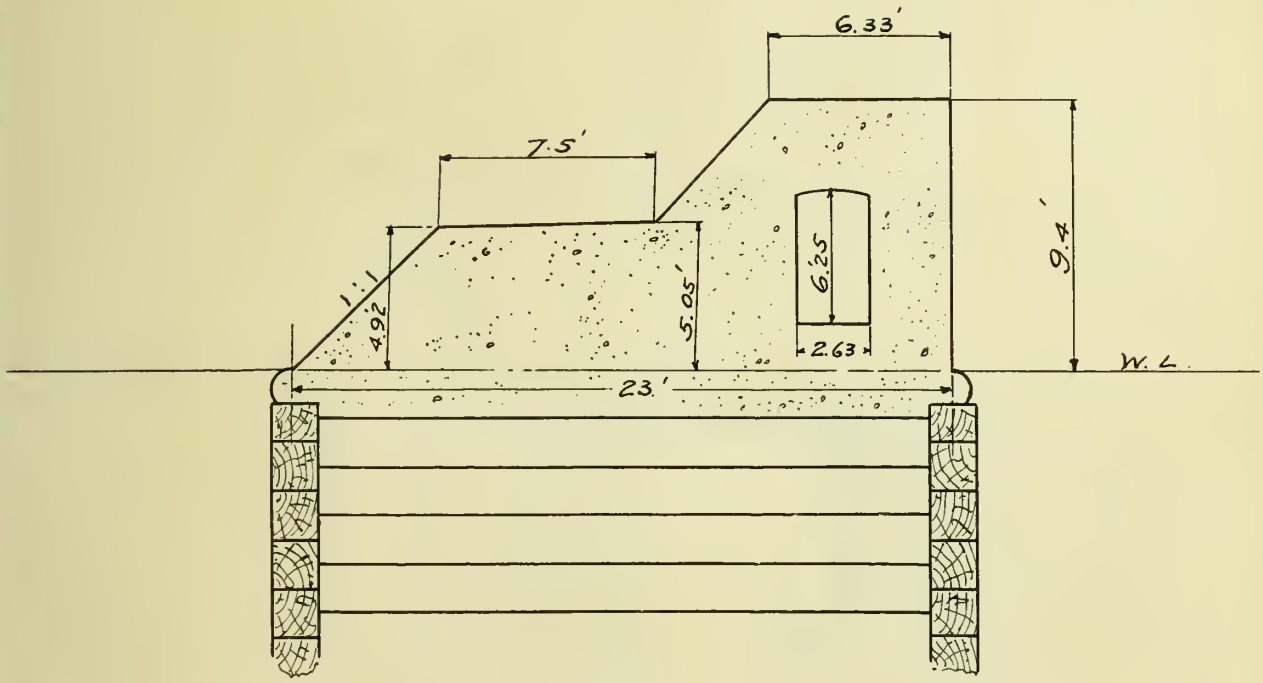


Elevation

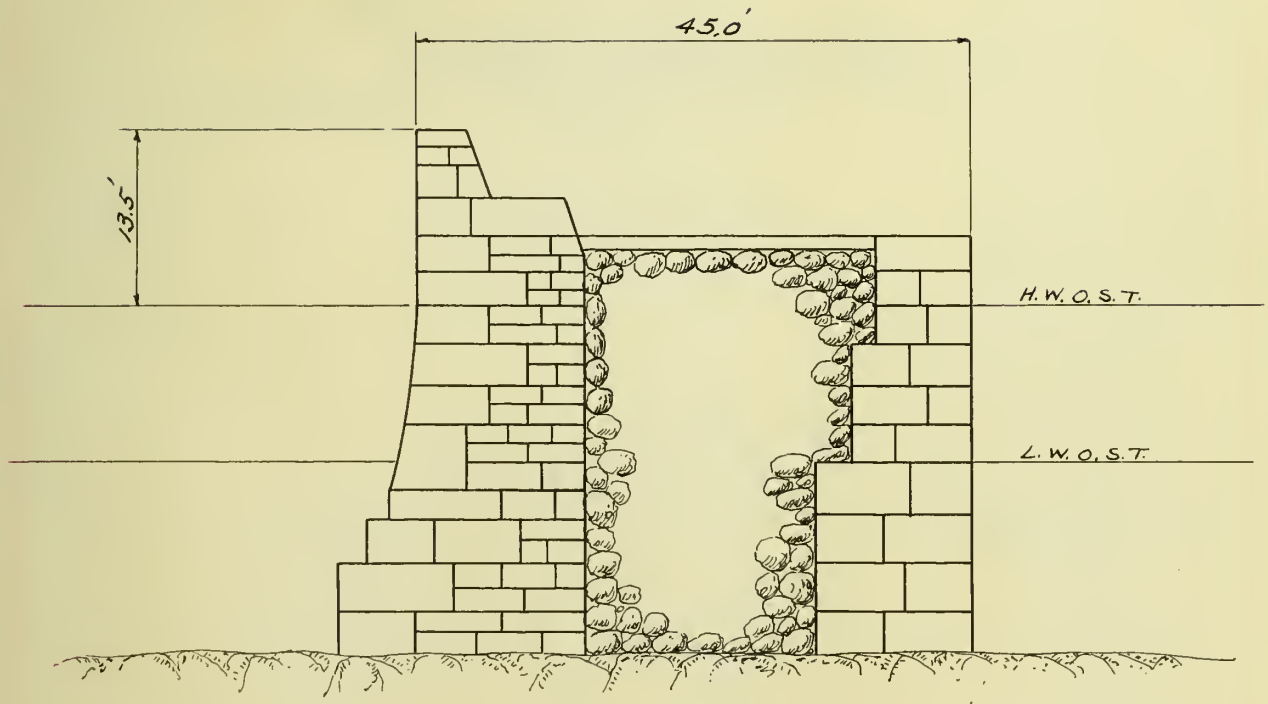


Section

Timber Crib Breakwater.

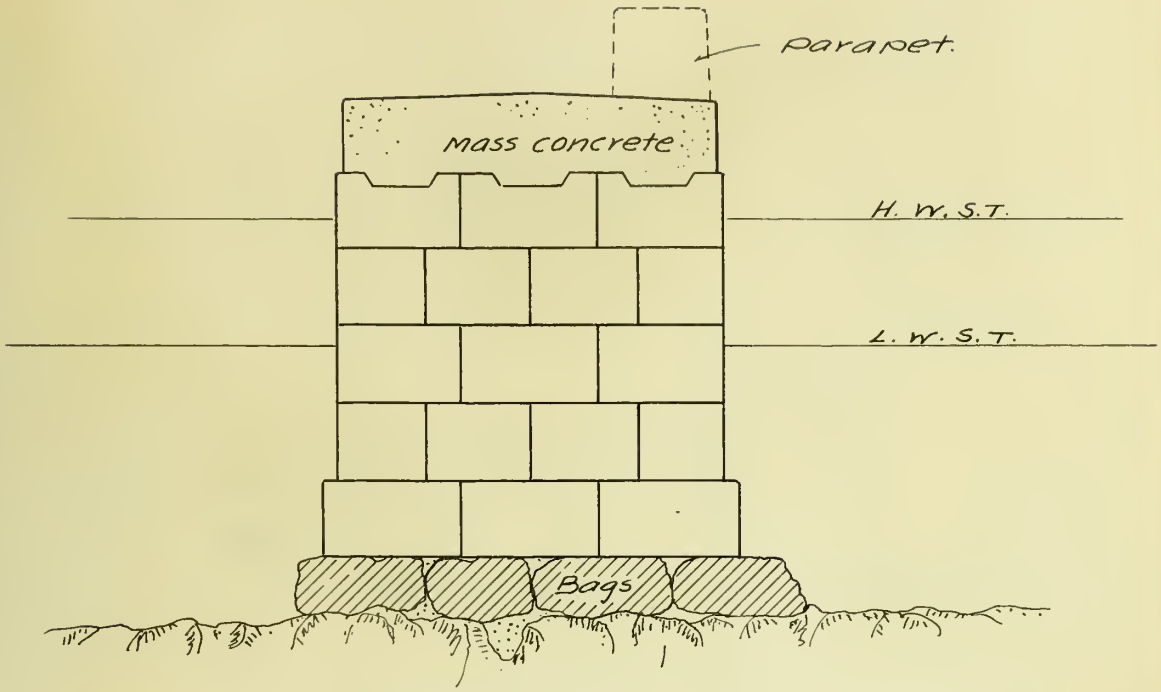


Concrete Superstructure
on Timber Crib.
at Marquett, Mich.

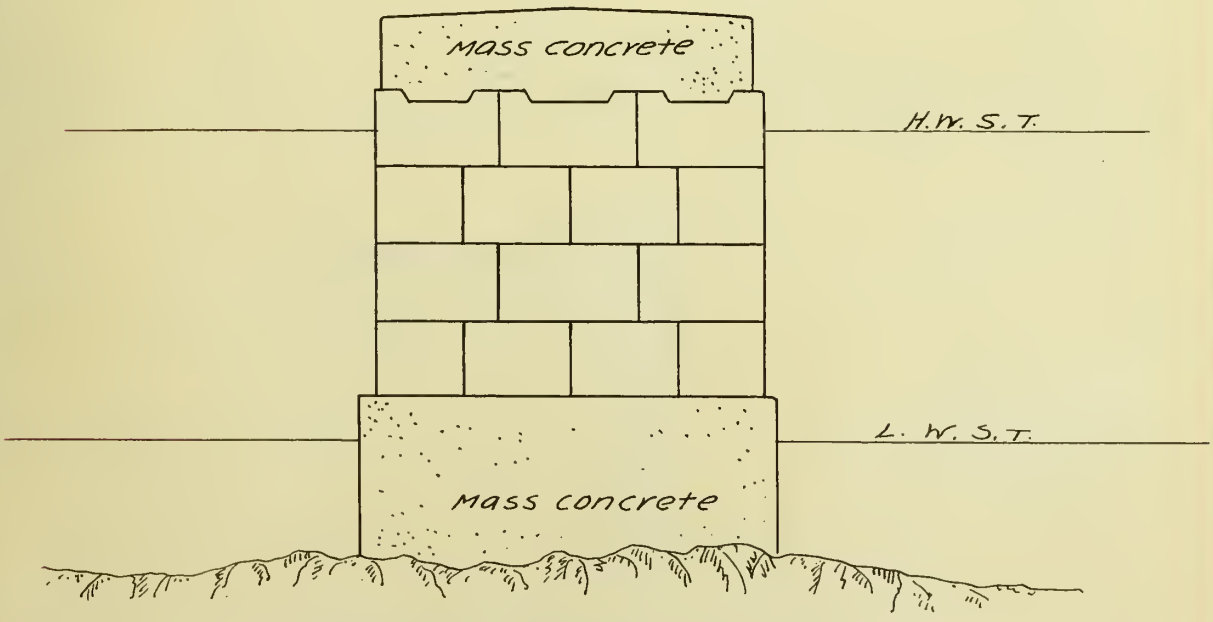


Breakwater of Masonry
with Rubble Hearting.

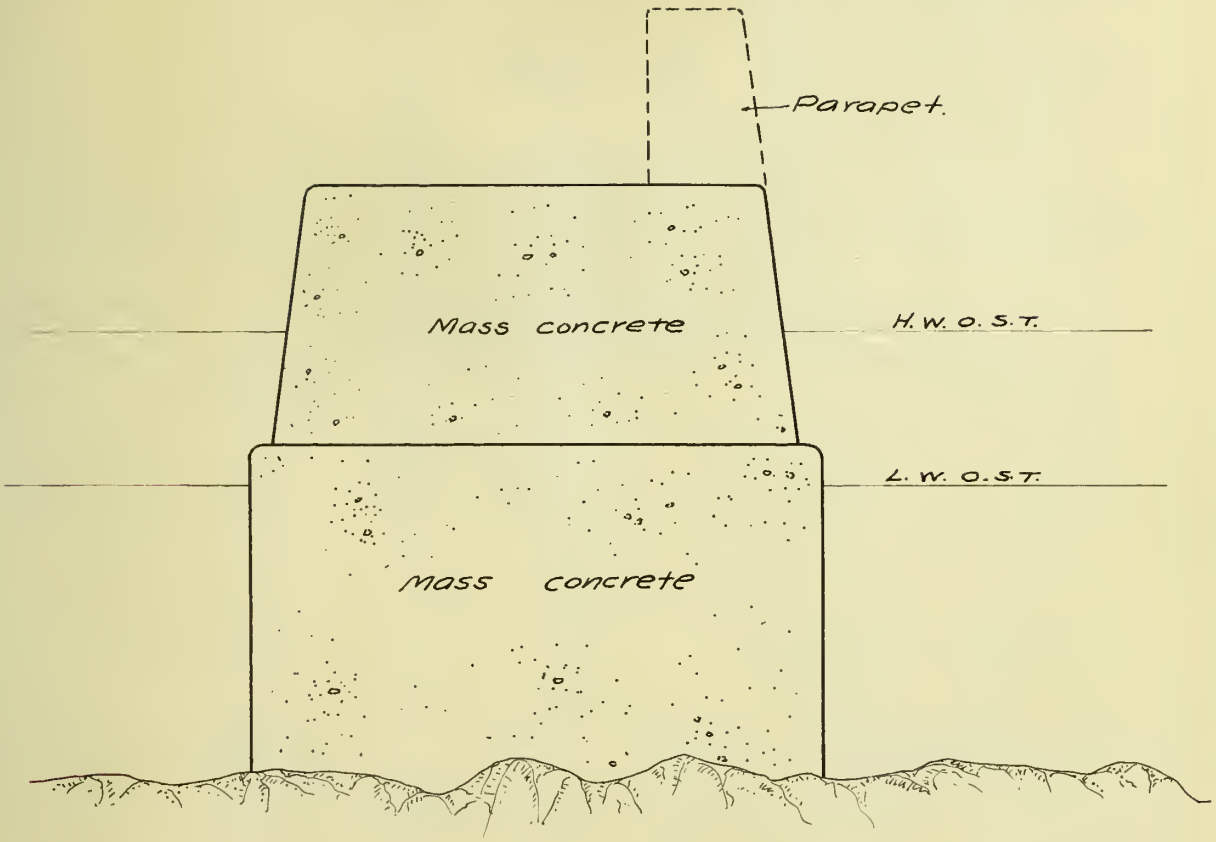
Filrush Breakwater.



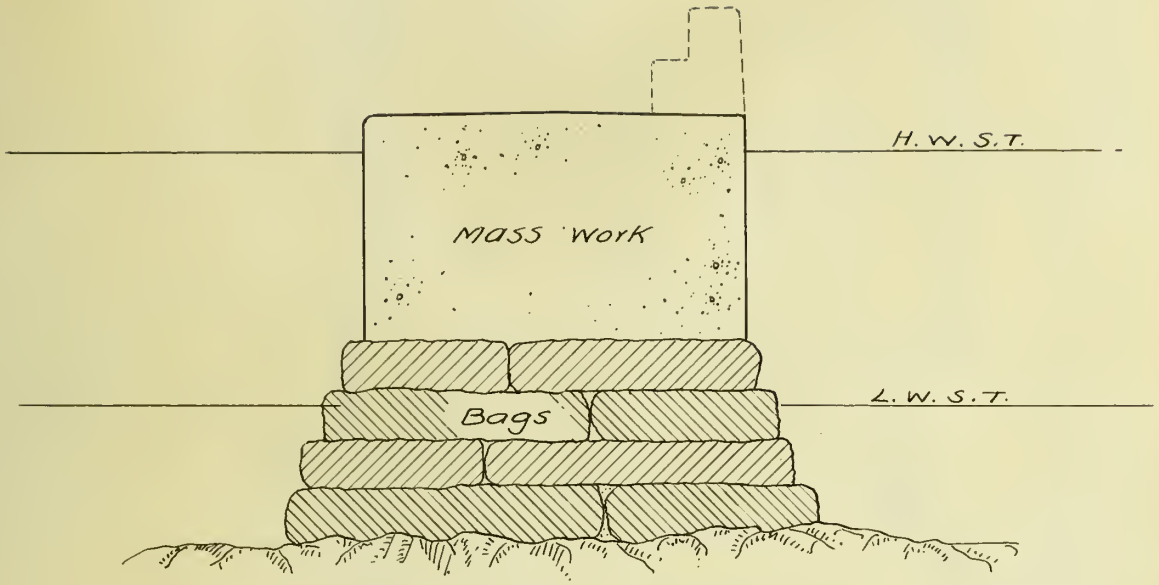
Concrete Blocks laid in
Horizontal Courses.



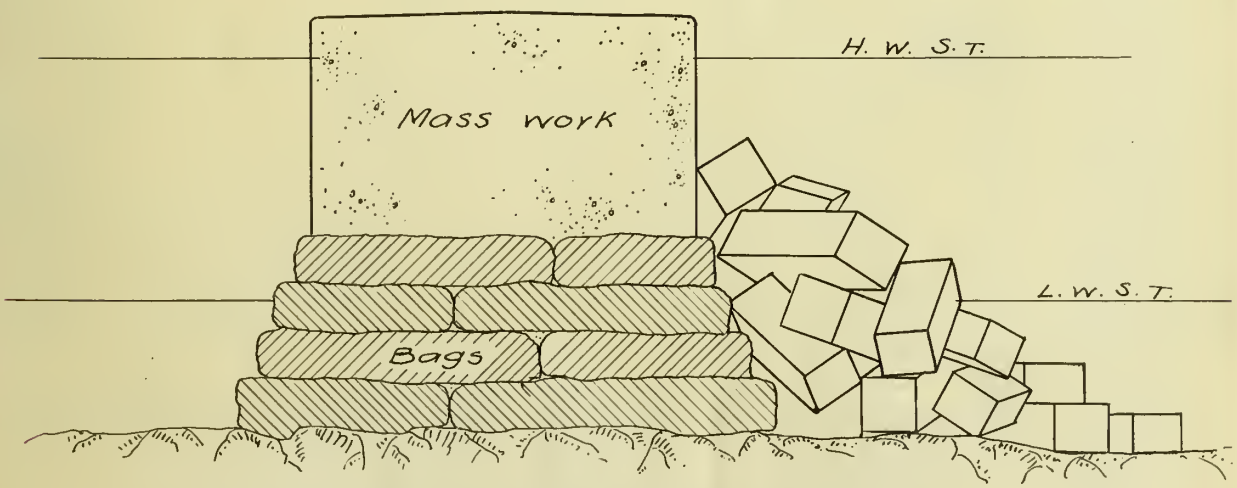
Concrete Blocks laid in
Horizontal Courses.



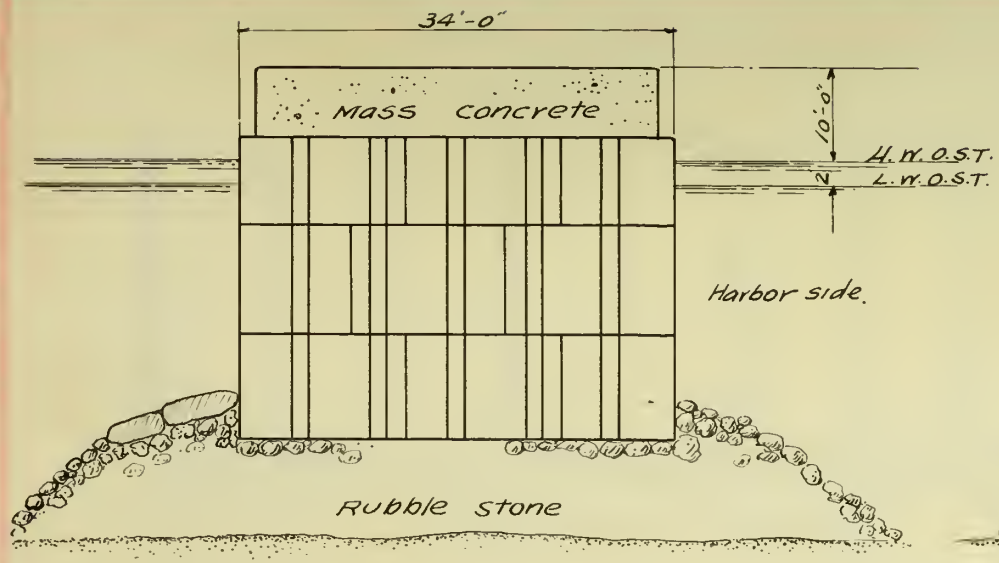
Breakwater of
Mass Concrete.



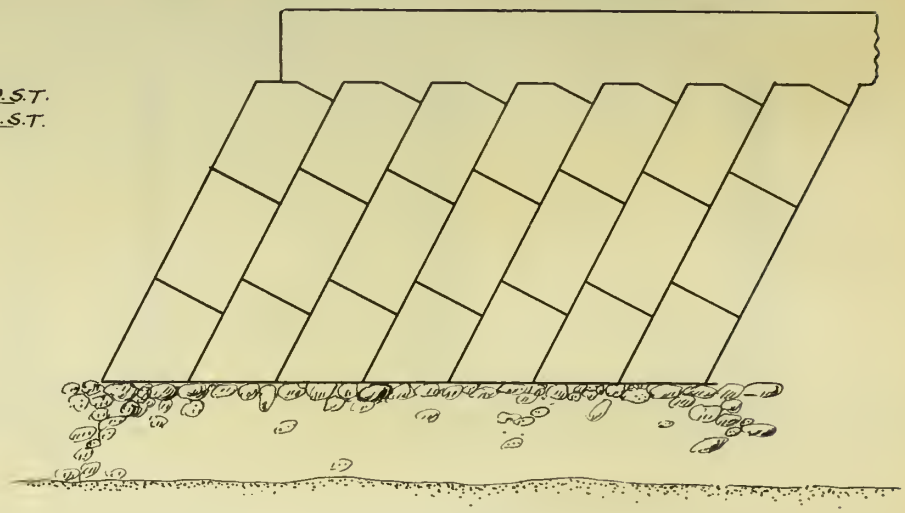
Mass Concrete Breakwater
with Concrete Bag Base.



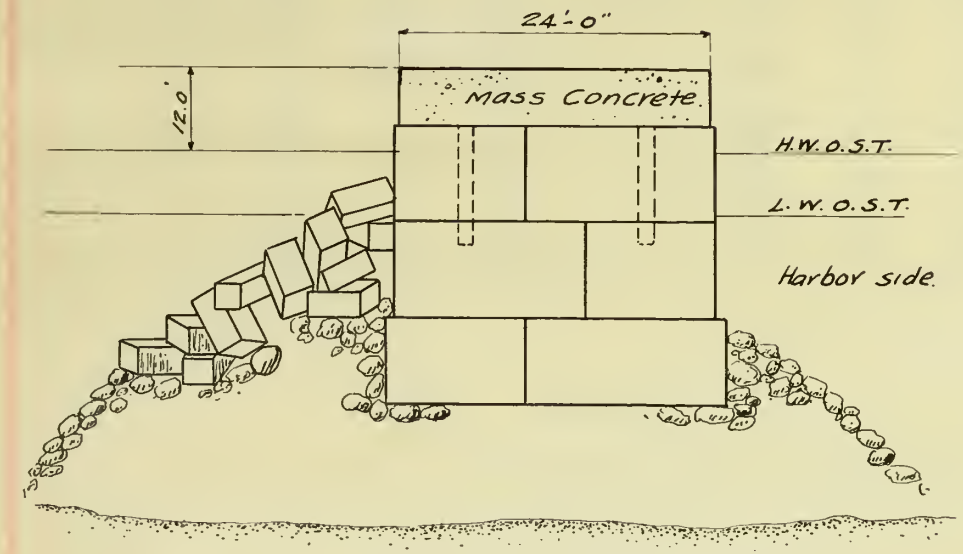
Mass Concrete Breakwater
with Concrete Bag Base.



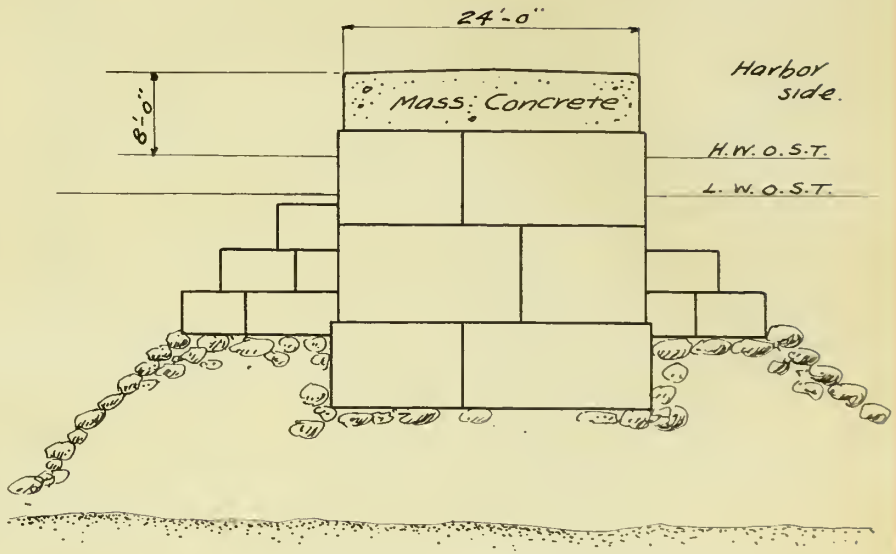
Colombo Breakwater.



Elevation.

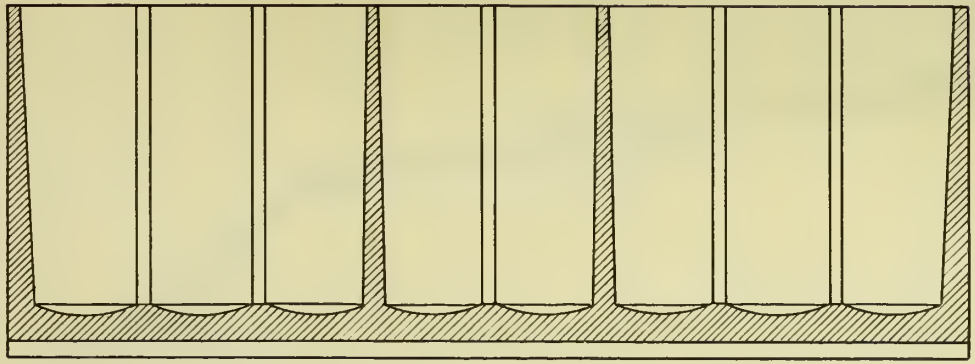


Madrus Breakwater.

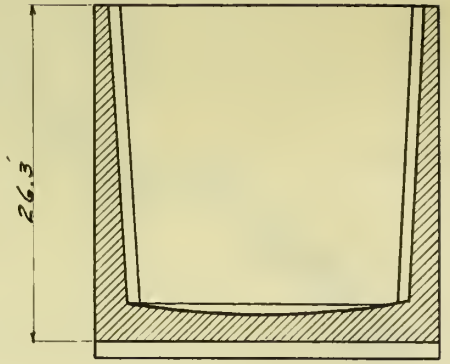


Otaru Breakwater.

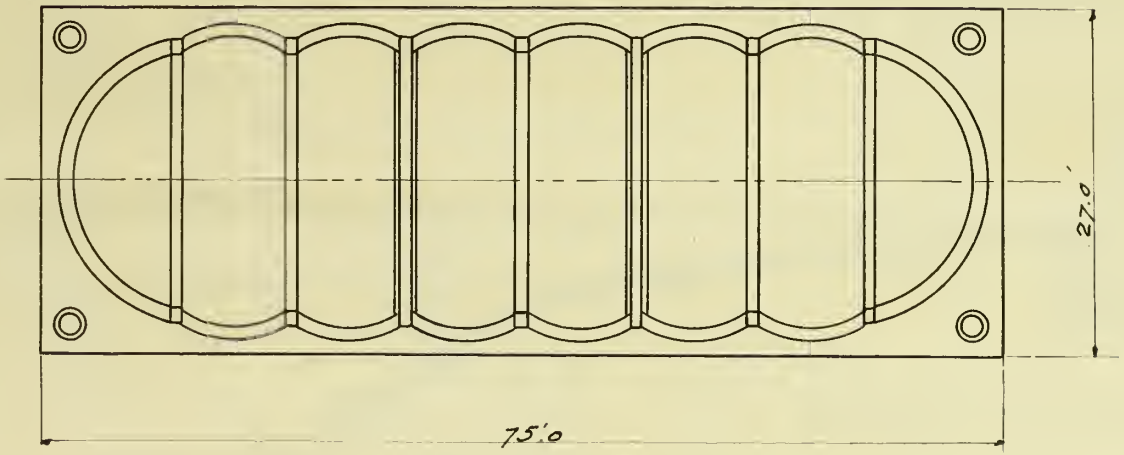
Breakwaters – Concrete Blocks laid in Sloping Courses.



Longitudinal section



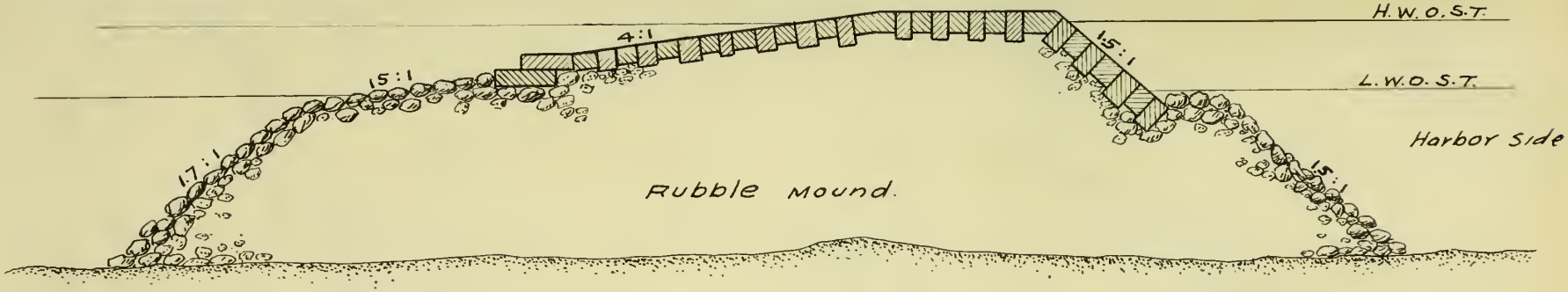
Cross Section.



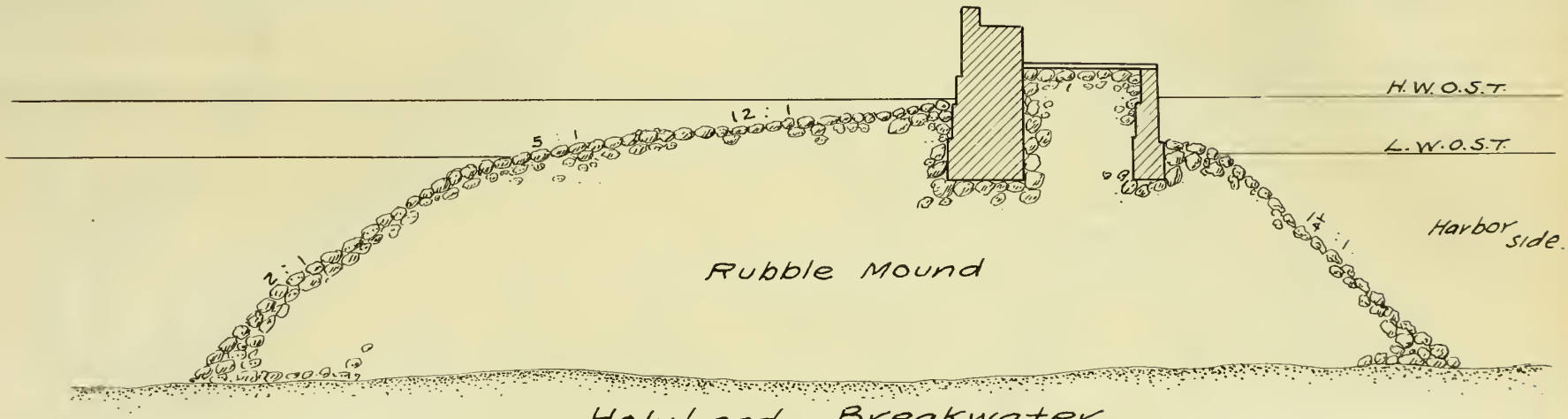
Plan.

Caisson at Zeebrugge.

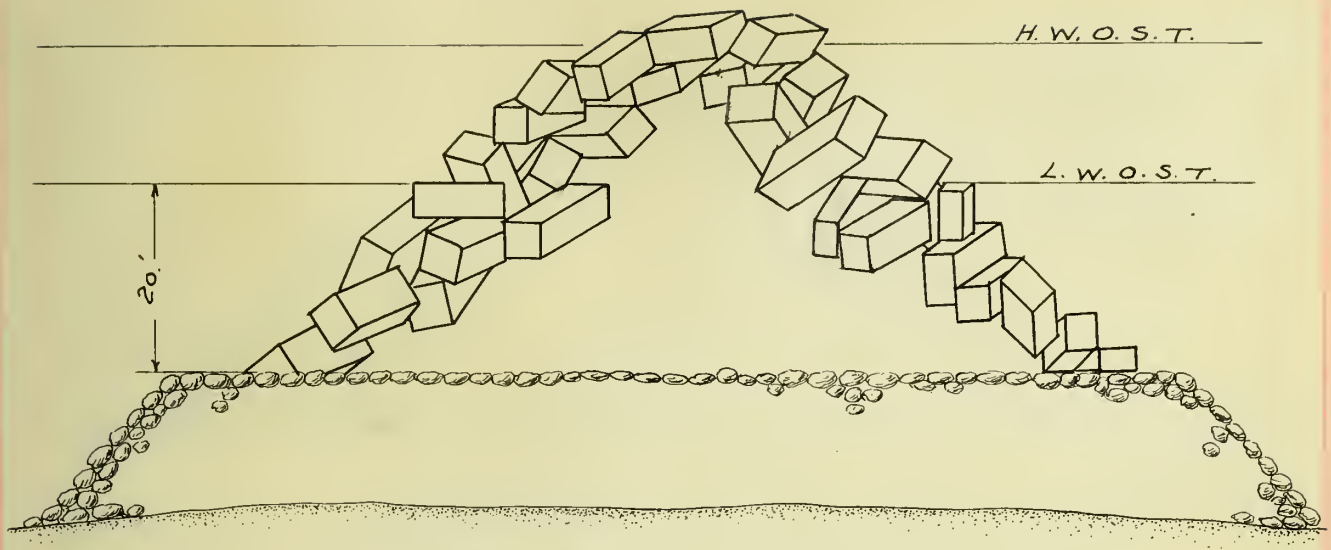
Plate XT.



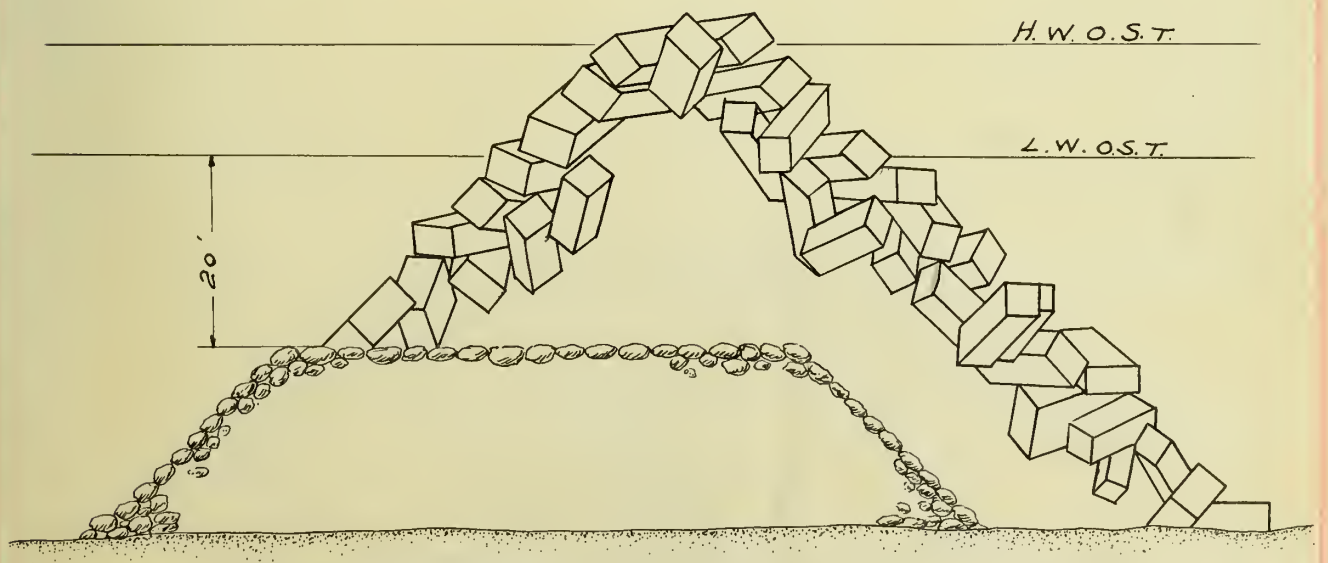
Plymouth Breakwater.



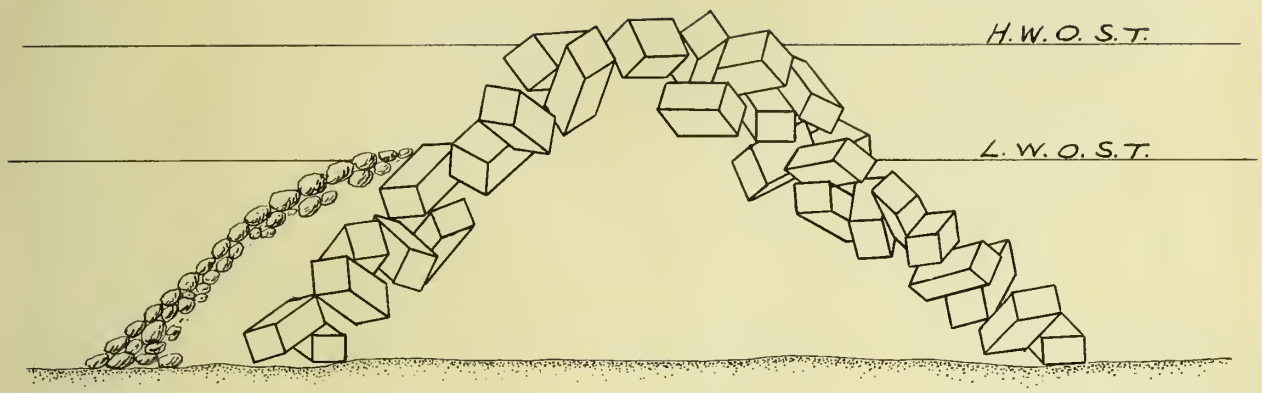
Holyhead Breakwater.



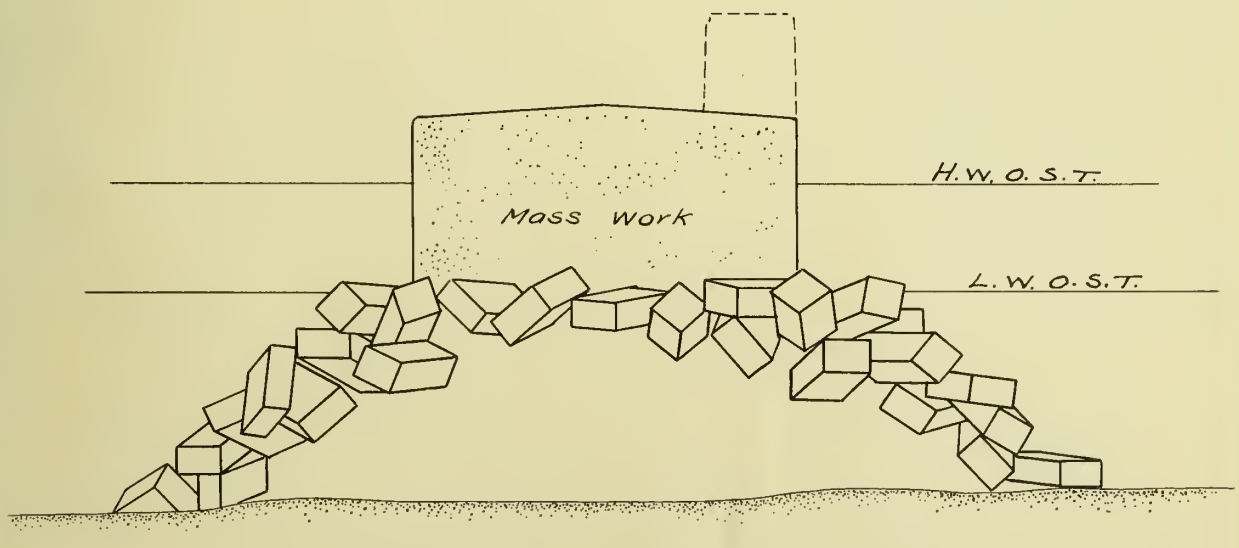
Mound Breakwater of Concrete Blocks
with Rubble Base.



Mound Breakwater of Concrete Blocks
with Rubble Base.



Mound Breakwater of Concrete Blocks and Rubble Stone.



Mound Breakwater of Concrete Blocks with Mass works.

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